



Solar Wind Earth Exchange Project 140200

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Final Report**

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14. ABSTRACT <p>The grant received from AFRL/AOFSR/EOARD funded the Solar Wind Earth Exchange Project (SWEEP) at Leicester University. The goal of SWEEP was to compare theoretical models of X-ray emission in the terrestrial magnetosphere caused by the Solar Wind Charge Exchange (SWCX) process with observations of this emission by the X-ray observatory, XMM-Newton. Terrestrial SWCX emission has the long term potential of enabling direct imaging of the magnetosphere by future wide field-of-view X-ray instruments. This research is an essential precursor by providing verification of expected emissivity levels. The grant funded a PDRA, Dr. Ian Whittaker, to perform the research, supervised by myself, Dr. Steven Sembay. Dr. Whittaker produced two first author papers arising from the research that have been published in the prestigious Journal of Geophysical Research (JGR) and Geophysical Research Letters (GRL). Results were also presented at AGU.</p>					
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Solar Wind Earth Exchange Project (SWEEP) – Final Report

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Abstract

The grant received from AFRL/AOFSR/EOARD funded the Solar Wind Earth Exchange Project (SWEEP) at Leicester University, UK. The goal of SWEEP was to compare theoretical models of X-ray emission in the terrestrial magnetosphere caused by the Solar Wind Charge Exchange (SWCX) process with observations of this emission by the X-ray observatory, XMM-Newton. Terrestrial SWCX emission has the long-term potential of enabling direct imaging of the magnetosphere by future wide field of view X-ray instruments. This research is an essential precursor by providing verification of expected emissivity levels. The grant funded a PDRA, Dr. Ian Whittaker, to perform the research, supervised by myself, Dr. Steven Sembay. Dr. Whittaker produced two first author papers arising from the research that have been published in the prestigious Journal of Geophysical Research (JGR) and Geophysical Research Letters (GRL). Results were also presented at AGU.

Project results and output

The primary published paper that composed the bulk of the SWEEP research and encompassed its major goals was

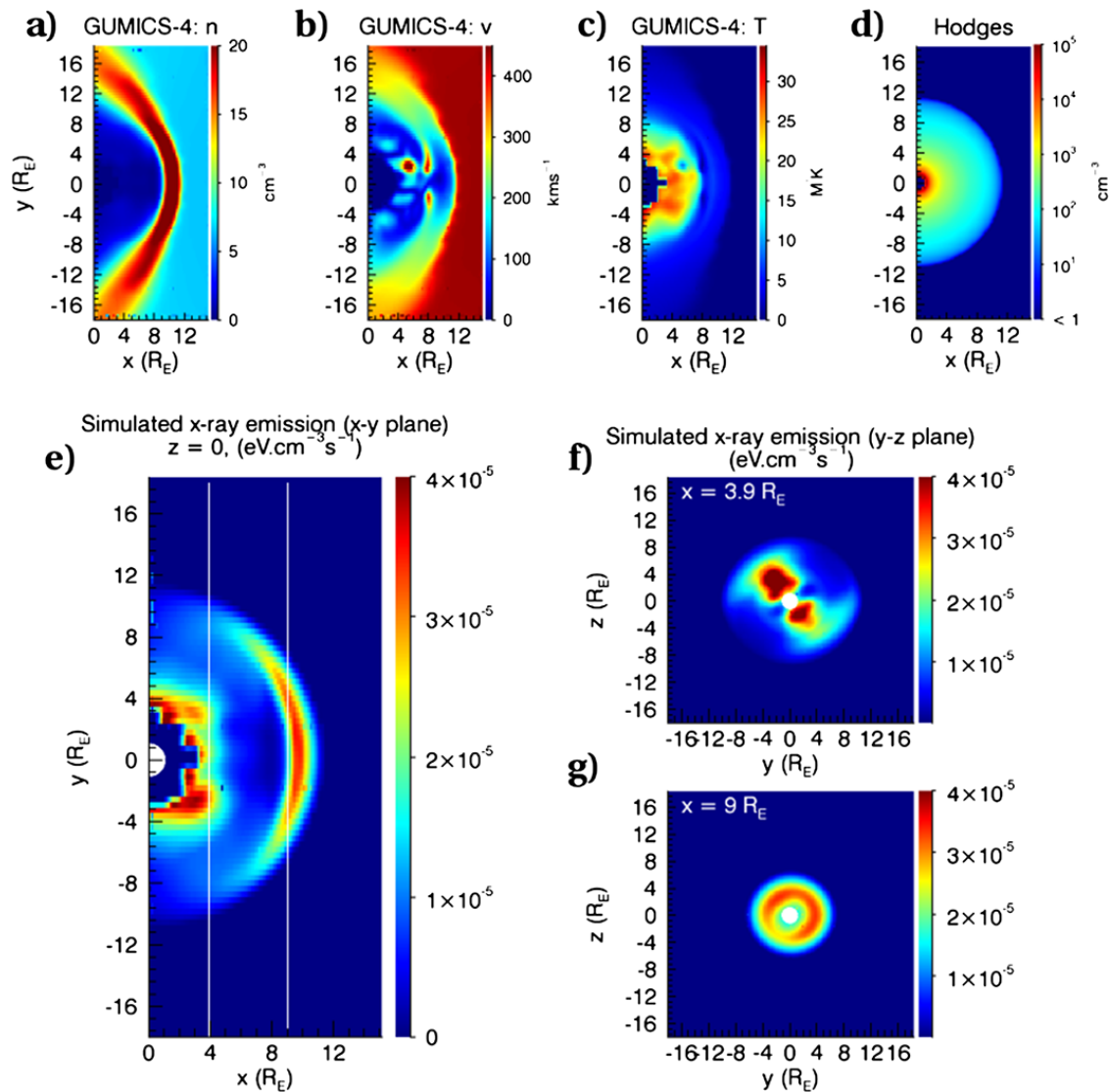
1) Whittaker, I, Sembay, S., Carter, J. A., Read, A., Milan, S. E., and Palmroth, M., “Modeling the magnetospheric X-ray emission from solar wind charge exchange with verification from XMM-Newton observations”, Journal of Geophysical Research: Space Physics, Volume 121, Issue 5, pp. 4158-4179, 2016

Publication date 05/2016

Abstract: An MHD-based model of terrestrial solar wind charge exchange (SWCX) is created and compared to 19 case study observations in the 0.5-0.7 keV emission band taken from the European Photon Imaging Cameras on board XMM-Newton. This model incorporates the Global Unified Magnetosphere-Ionosphere Coupling Simulation-4 MHD code and produces an X-ray emission datacube from O⁷⁺ and O⁸⁺ emission lines around the Earth using in situ solar wind parameters as the model input. This study details the

modeling process and shows that fixing the oxygen abundances to a constant value reduces the variance when comparing to the observations, at the cost of a small accuracy decrease in some cases. Using the ACE oxygen data returns a wide ranging accuracy, providing excellent correlation in a few cases and poor/anticorrelation in others. The sources of error for any user wishing to simulate terrestrial SWCX using an MHD model are described here and include mask position, hydrogen to oxygen ratio in the solar wind, and charge state abundances. A dawn-dusk asymmetry is also found, similar to the results of empirical modeling. Using constant oxygen parameters, magnitudes approximately double that of the observed count rates are returned. A high accuracy is determined between the model and observations when comparing the count rate difference between enhanced SWCX and quiescent periods.

Below we reproduce Figure 1 from this paper. This illustrates some of the work that formed the basis of the theoretical modelling of the SWEEP project. The figure panels are as follows; (a–d) The GUMICS-4 output for a single time step showing solar wind proton number density, bulk flow speed, and temperature with the final panel showing the equivalent Hodges neutral hydrogen density. Each of these panels shows a slice through the datacube in the x - y plane at $z = 0$. (e) The calculated X-ray emissivity in the x - y plane, with cuts taken to show the y - z plane at $x = 3.9 RE$, the magnetopause sits around a subsolar distance of $9 RE$, and the bow shock is at approximately $11 RE$.



The results from paper 1) led Dr. Whittaker to produce the following supplementary paper,

2) Whittaker, I. and Sembay, S.; "A comparison of empirical and experimental O^{7+} , O^{8+} , and O/H values, with applications to terrestrial solar wind charge exchange", *Geophysical Research Letters*, Volume 43, Issue 14, pp. 7328-7337, 2016

Publication date 07/2016

Abstract: Solar wind charge exchange occurs at Earth between the neutral planetary exosphere and highly charged ions of the solar wind. The main challenge in predicting the resultant photon flux in the X-ray energy bands is due to the interaction efficiency, known as the α value. This study produces experimental α values at the Earth, for oxygen emission in the range of 0.5-0.7 keV. Thirteen years of data from the Advanced Composition Explorer are examined, comparing O^{7+} and O^{8+} abundances, as well as O/H to other solar wind parameters allowing all parameters in the $\alpha O^{7,8+}$ calculation to be estimated based on solar wind velocity. Finally, a table is produced for a range of solar wind speeds giving average O^{7+} and O^{8+} abundances, O/H, and $\alpha O^{7,8+}$ values.

Pre-publication results of the SWEEP project were presented at AGU (2015) in the following conference proceeding;

3) Walach, M.T., Whittaker, I. Sembay, S, Carter, J.A. and Read, A.M; "Magnetospheric Solar Wind Charge Exchange - A Comparison Between the GUMICS-4 MHD Model and XMM-Newton", American Geophysical Union, Fall Meeting 2015, abstract #SM13E-2561

Abstract: The Solar Wind Earth Exchange Project (SWEEP) seeks to improve our understanding of the interaction of the solar wind with the Earth. X-ray emission resulting from charge exchange between oxygen in the solar wind and magnetospheric neutral hydrogen is modelled for a series of observations from XMM-Newton, an X-ray astronomical observatory. We use OMNI solar wind conditions, heavy ion composition data from ACE, the Hodges neutral hydrogen model and combine these with the GUMICS-4 MHD model to predict the global levels of X-ray emission from solar wind charge exchange (in the 0.5-0.7 keV band). The emission is then integrated along a line of sight and compared to the measured XMM-Newton sky background emissivity rates to determine the accuracy of these model predictions. Our results show that the magnitude of the integrated X-ray emissivity for both the modeled and observed flux is similar in a large number of cases, while the correlation of emission changes in detail between cases. We show that the accuracy of the oxygen density and relative charge state abundances is vital. The positional accuracy of the magnetopause is important as it forms the outer edge of the masking of the plasmasphere, including the cusps in our global emissivity rates. The derived position of the magnetopause and various masks are discussed with examples given, highlighting their relative accuracy. We also show the potential of X-ray emission for remote sensing of the magnetosphere, when used in combination with a wide field X-ray imaging system.

Summary

In my opinion this research was highly successful, generating two substantial and important papers. For this Dr. Whittaker is to be highly commended for his industry, enthusiasm and initiative.

The research has produced validation of the expected X-ray emissivity levels from SWCX in the terrestrial environment, but shown that input data from existing upstream solar wind monitors in combination with MHD modelling can be inadequate to explain all the features of the available observations in detail.

I would like to thank AFRL/AOSFR/EOARD for providing the means to support this project.